L&D HWG Fast Track Report for Continuous Turbulence NPRM & AC for 25.341
10 March 2000

ARAC WG Report Format

1 - What is the underlying safety issue to be addressed by the FAR/JAR?

To provide adequate strength for atmospheric turbulence encounters in service.

(a) The continuous turbulence requirements of 25.341(b) need to be revised to be consistent with the more current database and flight profile alleviation factor used for the 25.342(a) discrete gust requirements. Also remove the mission analysis criteria so as to provide a single consistent design requirement. There is a need to provide criteria for application to advanced flight controls with significant non-linearities.

(b) Due to events that have occurred in service, the NTSB (A-93-137), per Reference 1, has recommended changes in the turbulence/gust requirements for wing mounted engines. Reference 2 provides a record of the NTSB recommendations to the FAA and the FAA responses.

(c) The discrete gust requirements of 25.341(a) currently address altitudes up to 50,000 feet. Transport aircraft are being certified for altitudes above 50,000 feet, but less than 60,000 Feet. Therefore criteria are required for altitudes up to 60,000 feet.

The current requirements are in the opinion of the L&D HWG not unsafe. However it is felt that changes should be made to provide enhanced safety for future certification efforts.

2 - What are the current FAR and JAR standards relative to this subject?

Current FAR text:
25.341(b) The dynamic response of the airplane to vertical and lateral continuous turbulence must be taken into account. The continuous gust design criteria of appendix G of this part must be used to establish the dynamic response unless more rational criteria are shown.
(Appendix G offers a range of design requirements ranging from design envelope to mission analysis. In addition, the design envelope gust requirements may be reduced where the administrator finds that a design is comparable to a similar design with satisfactory service history.)

25.341(a)(5) ...... the reference gust velocity may be further reduced linearly from 44.0 fps EAS at 15,000 feet to 26.0 fps EAS at 50,000 feet.

Current JAR text:

25.341(b) The dynamic response of the airplane to vertical and lateral continuous turbulence must be taken into account. [See ACJ 25.341(b)]
(The ACJ offers the same range of design requirements, as does Appendix G.)

25.341(a)(5) (1) ...... the reference gust velocity may be further reduced linearly from 44.0 fps EAS at 15,000 feet to 26.0 fps EAS at 50,000 feet.

2a – If no FAR or JAR standard exists, what means have been used to ensure this safety issue is addressed?

The existing standards are being applied. The changes are intended to enhance the level of safety in particular by addressing special requirements for wing mounted engines

3 - What are the differences in the FAA and JAA standards or policy and what do these differences result in?:

Rule text and interpretation are essentially the same. Appendix G of the FAR and the interpretative materials in ACJ 25.341(b) are also essentially the same.

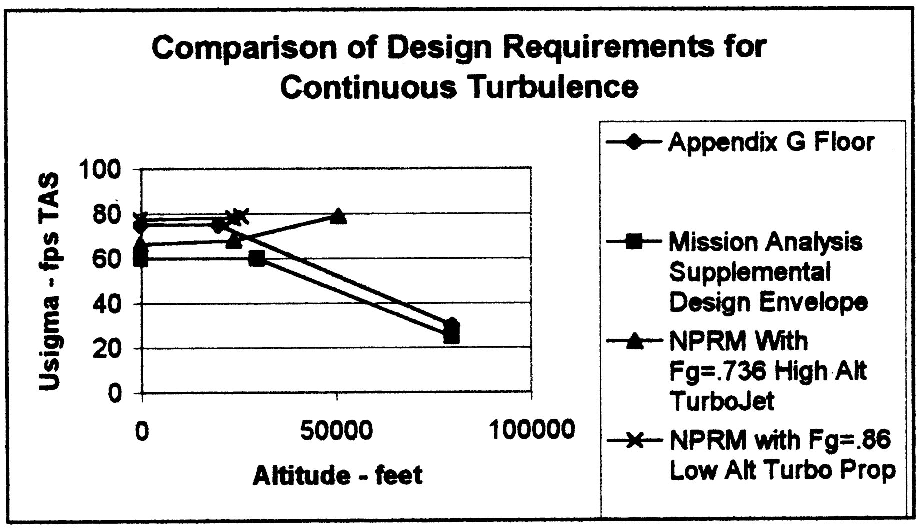
4 - What, if any, are the differences in the current means of compliance?

None.

5 – What is the proposed action?

Develop a new JAR and FAR continuous gust paragraph 25.341(b) that prescribes the new gust intensities, eliminates the mission analysis approach, sets forth a new standard for multi-axis gusts for wing mounted nacelles in accordance with the NTSB A-93-137 recommendation, and provides criteria for application to advanced flight controls with significant non-linearities. All of the requirements would be contained within the paragraph 25.341(b) and the existing Appendix G (FAR) and the current ACJ 25.341(b) would be cancelled.

The following chart compares the Usigma turbulence intensities for Appendix G and the NPRM. There is another maximum requirement in Appendix G that starts at 85 fps at altitudes up to 30,000 feet and then decreases linearly to 30 fps at 80,000 feet. However that requirement was rarely used due to the lower available options as shown in the chart.



Revise JAR and FAR 25.341(a) to extend the discrete gust velocities to an altitude of 60,000 feet.

Revise the FAR 25.1517 Vra speed to be consistent with the changes in design airspeeds brought about by the changes in the gust intensities in 25.341.

For each proposed change from the existing standard, answer the following questions:

6 - What should the harmonized standard be?

Move the Appendix G criteria to main rule text in 25.341(b). Revise Usigma turbulence levels, add a flight profile alleviation factor, and eliminate the mission analysis option. Add criteria for non-linear control systems.

Refer to the NPRM text for 25.341(b). The revised turbulence levels are based upon data as discussed in References 3 and 4.

Add multiaxis gust criteria for wing mounted engines

Refer to the NPRM text for 25.341(c). The criteria for phased vertical and lateral gust for wing mounted engines are based upon Reference 5. The criteria meet the intent of the NTSB A-93-137 recommendation.

Add considerations that are necessary for advanced flight controls

Refer to the NPRM text for 25.341(b)(4) and (5). The use of 40% of the U_σ values is selected in 25.341(b)(5) in order to minimize the amount of simulation time while achieving the same results.

Revise the gust intensities of 25.341(a)(5) to include altitudes up to 60,000 feet

Refer to the NPRM text of 25.341(a)(5). The only change is a linear extension of the gust velocity to 60,000 feet as opposed to the current maximum altitude of 50,000 feet.

Revise 25.1517 Vra to be consistent with the changes in design airspeeds brought about by the changes in gust intensities in 25.341

See the NPRM text for 25.1517. The change to Vra is based upon References 6 through 8.

Change 25.371, 25.373, AND 25.391 to properly reference the revised 25.341(a) and (b) paragraphs

See the NPRM text for these paragraphs.

7 - How does this proposed standard address the underlying safety issue (identified under #1)?

- Provides turbulence intensities and flight profile alleviation factor criteria that are compatible with the measured gust intensities and flight profile alleviation factor criteria that are currently in 25.341(a). The mission profile option is eliminated.
- Addresses the advanced flight control systems with significant non-linearities.
- Sets forth a multi-axis gust requirement for wing mounted nacelles to satisfy the NTSB A-93-137 recommendation.
- Extends the discrete gust velocities to 60,000 feet to cover the maximum altitudes at which transport aircraft are currently being certified.

The current turbulence velocities in Appendix G are not compatible with the database from which the current discrete gust velocities of 25.341(a) are derived. Also, there is agreement within the L&D HWG that one of the alternatives (mission analysis) for addressing continuous turbulence should be deleted in order to provide a singular design requirement. The rationale is that mission analysis is very sensitive to many assumptions made at the time the aircraft is designed. In-service usage of the aircraft may vary from the design assumptions.

There have also been difficulties in interpreting the gust requirements as they apply to advanced flight controls with significant non-linearities. Criteria and advisory material are now provided by the draft NPRM and AC.

In addition, the current requirement does not require the consideration of multi-axis phased gusts as recommended in NTSB Recommendation A-93-137. Such criteria are provided by the draft NPRM and AC.

The current 25.341(a)(5) only addresses gust velocities for altitudes up to 50,000 feet. Since there are aircraft being certified above that altitude, gust velocities have been provided for altitudes up to 60,000 feet.

8 - Relative to the current FAR, does the proposed standard increase, decrease, or maintain the same level of safety? Explain.

The analytical methodology is improved and requires a full dynamic response analysis of the airplane, including multi-axis dynamic response of wing mounted nacelles.

In addition, the mission analysis method would be eliminated since it could allow a reduction in strength under certain mission assumptions.

The level of safety is enhanced by

- Defining requirements for more comprehensive dynamic analysis using a better representation of the atmospheric turbulence
- Providing criteria for non-linear automatic control systems
- Defining muti-axis phased gust requirements for wing mounted engines
- Extending the discrete gust requirements to an altitude of 60,000 feet

9 - Relative to current industry practice, does the proposed standard increase, decrease, or maintain the same level of safety? Explain.

Increased because of the measures described in 8.

10 - What other options have been considered and why were they not selected?:

The only alternatives considered for the revision to the gust intensities were to either retain the existing ones or adopt the more recent measurements. The new intensities were deemed to more accurately represent the actual atmosphere. Also, manufacturers trial analyses did not result in excessive design penalties.

Several alternative proposals were considered in order to satisfy the NTSB A-93-137 recommendation. A multiaxis phased discrete gust approach, a round-the-clock gust criterion, an uncorrelated combined power spectral density method, and ignoring it all together. The round-the-clock approach alone was not considered to be a true multiaxial gust and for some configurations would not necessarily provide adequate loads. The uncorrelated and combined power spectral density method was deemed to be unrealistically conservative and too costly and the proposal to ignore the recommendation did not obtain group consensus. The final method is a simplified multiaxial discrete gust method backed up with a supplementary round-the-clock gust criterion.

11 - Who would be affected by the proposed change

Airplane manufacturers will be most affected.

12 - To ensure harmonization, what current advisory material (e.g., ACJ, AMJ, AC, policy letters) needs to be included in the rule text or preamble?

See the rule text and advisory material as attached.

13 - Is existing FAA advisory material adequate? If not, what advisory material should be adopted?

Existing advisory material is not adequate.
A new advisory circular AC 25.341-1 is proposed. (See attachment)

14 - How does the proposed standard compare to the current ICAO standard?

The proposal is more detailed and comprehensive but enveloped by the general ICAO gust requirement in Annex 8, Part III, par. 3.3.2. *"Gust loads shall be computed for vertical and horizontal gust velocities and gradients which statistics or other evidence indicate will be adequate for the anticipated operating conditions."*

15 - Does the proposed standard affect other HWG's?

No.

16 - What is the cost impact of complying with the proposed standard?

For a new design the costs should be minimal. To apply the criteria to an existing or derivative model could result in significant costs.

17. - If advisory or interpretive material is to be submitted, document the advisory or interpretive guidelines. If disagreement exists, document the disagreement.

Advisory Circular 25.341-1 is submitted and is attached. The AC provides not only guidance for the continuous gust requirement of this proposal, but also provides guidance for the discrete dynamic gust requirement previously published in amendment 25-86. There is no disagreement.

18.- -Does the HWG wish to answer any supplementary questions specific to this project?

No

19. – Does the HWG want to review the draft NPRM at "Phase 4" prior to publication in the Federal Register?

Yes

20. – In light of the information provided in this report, does the HWG consider that the "Fast Track" process is appropriate for this rulemaking project, or is the project too complex or controversial for the Fast Track Process? Explain.

This issue is too complex for the Fast Track Process. The concepts are difficult and the issues are complex and are likely to generate public comment. The working group will need to continue to provide input for the cost/benefit analysis and will likely need to be tasked to address comments.

References

1. NTSB Letter to David Hinson. Dated 15 November 1993.
2. NTSB Recommendations to FAA amd FAA Responses Report. Dated 17 April 1998.
3. Letter report titled: Derivation of Continuous Turbulence Design Intensities From Operational Data. Dated November 1996. Authored by Vic Card.
4. FAA Tech Center Report DOT/FAA/CT-94/21 Reanalysis of European Flight Loads Data. Dated May 1994
5. Report DOT/FAA/AR-99/62, Titled: Studies Of Time-Phased Vertical and Lateral Gusts: Development of Multiaxis One-Minus-Cosine Gust Model. Dated: October 1999, Final Report.
6. Letter from V. Card to Miss J.L. Denning, Chairman of JAA Flight Study Group. Subject: Harmonisation of Rough Air Speed Requirements, dated: 11 August 1997.
7. Letter from G. D, Weightman, Chairman of JAA Flight Study Group to V. Card, subject: Harmonisation of Rough Airspeed Requirements, dated: 26 May 1998.
8. Document FWP 581by F. Iannarelli and C. Clerc, subject: Harmonisation of Rough Airspeed Requirements, dated: 30 Jan 1998.

[4910-13]

DEPARTMENT OF TRANSPORTATION

Federal Aviation Administration

[14 CFR part 25]

[Docket No. ; Notice No.]

RIN:

Revised Requirements for Gust and Continuous Turbulence Design Loads

AGENCY: Federal Aviation Administration, DOT.

ACTION: Notice of proposed rulemaking.

SUMMARY: This notice proposes to revise the continuous turbulence design loads of the Federal Aviation Regulations (FAR) for transport category airplanes by incorporating changes developed in co-operation with the Joint Aviation Authorities (JAA) of Europe and the U.S., Canadian and European aviation industries through the Aviation Rulemaking Advisory Committee (ARAC). This action is necessary because recent measurements of derived gust intensities in actual operation show that the current requirements do not accurately account for the distribution of turbulence in the atmosphere. Also, one of the optional methodologies for treating continuous turbulence (i.e. mission analysis) in the current rule is eliminated since it is overly sensitive to small changes in the definition of aircraft mission. In addition to these issues regarding continuous turbulence, The National Transportation Safety Board (NTSB) has provided a Safety Recommendation, A-93-137 which raises concerns the potential for combined vertical and lateral discrete gusts. This proposal is intended to improve the requirements for continuous turbulence by revising the turbulence intensity criteria, eliminating the mission analysis method, providing a multi-axis discrete gust criterion, and reorganizing and clarifying the rule.

DATES: Comments must be received on or before [insert a date 120 days after the date of publication in the Federal Register]

ADDRESSES: Comments on this notice may be mailed in triplicate to: Federal Aviation Administration (FAA), Office of the Chief Counsel, Attention: Rules Docket (AGC-10), Docket No. , 800 Independence Avenue SW., Washington, DC 20591; or delivered in triplicate to: Room 915G, 800 Independence Avenue SW., Washington, DC 20591. Comments delivered must be marked Docket No. . Comments may also be submitted electronically to nprmcmts@mail.hq.faa.gov. Comments may be examined in Room 915G weekdays, except Federal holidays, between 8:30 a.m. and 5:00 p.m. In addition, the FAA is maintaining an information docket of comments in the Transport Airplane Directorate (ANM-100), FAA, 1601 Lind Avenue SW., Renton, WA 98055-4056. Comments in the information docket may be examined weekdays, except Federal holidays, between 7:30 a.m. and 4:00 p.m.

FOR FURTHER INFORMATION CONTACT: James Haynes, Airframe and Propulsion Branch, ANM-112, Transport Airplane Directorate, Aircraft Certification Service, FAA, 1601 Lind Avenue, SW., Renton, WA 98055-4056; telephone (206) 227-2131.

SUPPLEMENTARY INFORMATION

Comments Invited

Interested persons are invited to participate in this proposed rulemaking by submitting such written data, views, or arguments as they may desire. Comments relating to any environmental, energy, or economic impact that might result from adopting the proposals contained in this notice are invited. Substantive comments should be accompanied by cost estimates. Commenters should identify the regulatory docket or notice number and submit comments in triplicate to the Rules Docket address above. All comments received on or before the closing date for comments will be considered by the Administrator before taking action on this proposed rulemaking. The proposals contained in this notice may be changed in light of comments received. All comments received will be available in the Rules Docket, both before and after the comment period closing date, for examination by interested persons. A report summarizing each substantive public contact with FAA personnel concerning this rulemaking will be filed in the docket. Persons wishing the FAA to acknowledge receipt of their comments must submit with those comments a self-addressed, stamped postcard on which the following statement is made: "Comments to Docket No. ." The postcard will be date/time stamped and returned to the commenter.

Availability of NPRM

An electronic copy of this document may be downloaded using a modem and suitable communications software from the FAA regulations section of the Fedworld electronic bulletin board service (telephone: 703-321-3339), the Federal Register's electronic bulletin board service (telephone: 202-512-1661), or the FAA's Aviation Rulemaking Advisory Committee Bulletin Board service (telephone: 202-267-5984).

Internet users may reach the FAA's web page at http://www.faa.govv or the Federal Register's web page at http://www.access.gpo/su_docs for access to recently published rulemaking documents.

Any person may obtain a copy of this notice by submitting a request to the Federal Aviation Administration, Office Rulemaking, ARM-1, 800 Independence Avenue SW., Washington, DC 20591; or by calling (202) 267-9680. Communications must identify the notice number of this NPRM. Persons interested in being placed on a mailing list for future rulemaking documents should also request a copy of Advisory Circular No. 11-2A, Notice of Proposed Rulemaking Distribution System, that describes the application procedures.

Background

The manufacturing, marketing and certification of transport airplanes is increasingly an international endeavor. In order for U. S. Manufacturers to export transport airplanes to other countries the airplane must be designed to comply, not only with the U.S. airworthiness requirements for transport airplanes (14 CFR part 25), but also with the airworthiness requirements of the countries to which the airplane is to be exported.

The European countries have developed a common airworthiness code for transport airplanes that is administered by the Joint Aviation Authorities (JAA) of Europe. This code is the result of a European effort to harmonize the various airworthiness codes of the European countries and is called the Joint Aviation Requirements (JAR)-25. It was developed in a format similar to part 25. Many other countries have airworthiness codes that are aligned closely to part 25 or to JAR-25, or they use these codes directly for their own certification purposes. Since 1988, the FAA and JAA have been working toward complete harmonization of JAR-25 and part 25.

The Aviation Rulemaking Advisory Committee (ARAC) was established by the FAA on February 15, 1991, with the purpose of providing information, advice, and recommendations to be considered in rulemaking activities. The FAA and JAA are continuing to work toward the harmonization of JAR-25 and part 25 by assigning ARAC specific tasks.. By notice in the Federal Register (59 FR 30081, June 10, 1994), the FAA assigned several new tasks to an ARAC working group of industry and government structural loads specialists from Europe, the United States, and Canada. Task 2 of this charter concerned the requirement to account for continuous turbulence loads. The assigned task was to review the current requirement for continuous turbulence in part 25 and JAR-25 in light of recent revisions to the discrete gust requirement of Amendment 25-86 (61 FR 5218) in order to determine if the continuous turbulence requirement was still needed and if it was in need of revision to be consistent with the new discrete gust requirement of § 25.341(a). The ARAC Loads and Dynamics Harmonization working group has completed its work for this task and has made recommendations to the FAA by letter dated ______________.

The current requirement to account for the loads produced by continuous turbulence (sometimes referred to as continuous gusts) was proposed by the FAA in Notice 68-18 (33 FR 11913, August 22, 1968). This proposal was the culmination of a research effort by the U.S. aviation industry under a contract by the FAA to develop methods for treating loads resulting from flight in continuous turbulence. The rules in effect at that time required only the consideration of the response of the airplane to discrete gusts. The FAA stated in Notice 68-18 that the discrete gust requirement accounted for the flexibility of the airplane but not necessarily the combination of elastic and rigid body motions. The basic objective of the FAA sponsored research effort was to develop methods of accounting for continuous turbulence loads by considering the statistical nature of turbulence in combination with both the elastic and rigid body modes of the airplane. The results of that effort were published in FAA Technical Reports ADS-53 and ADS-54 in 1966. Subsequently the FAA amended part 25 to require the consideration of loads arising from continuous turbulence (Amendment 25-23, 35 FR 5665, April 8, 1970).

Amendment 25-23 added a new paragraph, § 25.305(d), that required the dynamic response of the airplane to continuous turbulence be taken into account. No methodology or advisory material were provided for showing compliance, however, FAA Reports ADS-53 and ADS-54 suggested two methods in use by aircraft manufacturers. These methods were considered acceptable by FAA. Later, in 1975, the FAA proposed these methods as means of compliance in an Appendix to part 25 (Notice 75-27, 40 FR 24802, March 7, 1975). The FAA subsequently amended part 25 by adding appendix G (Amendment 25-54, 45 FR 60154, September 11, 1980) that set forth the two methodologies (design envelope and mission analysis) and specified the levels of required gust intensities for use in design. Section 25.305(d) was also changed by amendment 25-54 to require that the criteria presented in Appendix G be used unless more rational criteria were shown.

The gust intensities provided for use with the design envelope method have been the subject of contention and debate since the publication of the proposal for Appendix G. Several commenters to that proposal objected to the proposed Appendix G, stating that the atmospheric model was not yet sufficiently defined and that the analyses techniques were still developing. The FAA recognized these shortcomings but, in the interest of safety, decided to go ahead with the requirement with the intention of refining the criteria as more information became available. The requirement provided a sea level value for gust intensity of 85 fps for the design envelope method, however, this could be reduced to 75 fps by using a comparison with a dynamically similar model in which 75 fps is shown to be adequate by service experience. The phrase "dynamically similar model" has been subject to a wide range of interpretations and has resulted in non uniform application of the rule. In addition, the concept of adjusting the gust intensity based on dynamic similarity with another airplane is questionable since the need for a different gust intensity is related more to the intended operation of the airplane, rather than its dynamic characteristics.

The alternative mission analysis method has also been the subject of considerable debate and controversy. With this method, the manufacturer must define a mission for the airplane which includes range, altitude, payload and other operational variables. Then, using a statistical model of the atmosphere, the manufacturer must show that the design strength will not be exceeded, within a certain probability, during the airplane operational life. Predicting the mission is not always reliable since missions can change after the airplane goes into operation. Furthermore, the mission analysis design loads are sensitive to small changes in the definition of the aircraft mission. Therefore, small variations in approach can provide inconsistent results.

Additional shortcomings in the current continuous turbulence requirement have been brought to light by experience in applying the current criteria, experience in service, and by the changing design features of transport airplanes. Many transport airplanes now incorporate automatic flight control systems and other features that can result in significant non-linearity's while the methodology normally employed for continuous turbulence is inherently linear.

Efforts to better define the atmospheric model have continued since the adoption of Appendix G. Recent flight measurement programs conducted by FAA and the National

Aeronautics and Space Administration (NASA) have been aimed at utilizing measurements from the digital flight data recorders (DFDR) to derive gust load design information for airline transport airplanes. The Civil Aviation Authority (CAA) of the United Kingdom has conducted a comprehensive DFDR gust measurement program for transport airplanes in airline service. The program, called CAADRP (Civil Aircraft Airworthiness Data Recording Program), has resulted in an extensive collection of reliable gust data which has provided an improved insight into the distribution of gusts in the atmosphere.

Recently, the regulatory authorities and the aviation industries of the U.S., Canada and Europe have engaged in studies with the aim of finding a single gust design methodology that would account for both discrete gust and continuous turbulence. Although several promising methods are still under study, no single method is considered to be sufficient, at this time, for treating both phenomena. The FAA believes that it is necessary to proceed with the improvement and harmonization of the current gust criteria for both safety and economic reasons. Therefore, ARAC has proceeded with developing harmonized improvements to the continuous turbulence and discrete gust design load conditions as separate requirements.

The FAA recently revised § 25.341 of the part 25 (Amendment 25-86, 61 FR 5218, dated February 9, 1996) to provide a revised discrete gust methodology along with a refined gust distribution model of the atmosphere based on the CAADRP data. These criteria were set forth in paragraph (a) of § 25.341. The continuous turbulence requirement was moved, without change, from § 25.305(d) to § 25.341(b) so that all the gust design criteria, including continuous turbulence, would be specified in the same section of part 25.

ARAC believes, and the FAA agrees, that a continuous turbulence criterion is still needed in addition to the discrete gust criterion since it accounts for the response to totally different, but still realistic, atmospheric characteristics. However, it is recognized that the current turbulence intensity model is inconsistent with the CAADRP data, and with the new atmospheric model prescribed for discrete gusts, and is in need of updating to accommodate modern transport airplanes.

Discussion

The proposed requirement includes a revision to the gust intensity model used in the design envelope method for continuous turbulence, elimination of the mission analysis method, provisions for treating non-linearities, and reorganization and clarification of the requirement.

The FAA proposes to retain the design envelope criterion, but with a revised gust intensity distribution with altitude. The proposed gust intensities are based on analysis of gust measurements from the CAADRP program. The CAADRP data is the most recent gust information available and it represents measurements of gusts and turbulence on transport airplanes in actual operation. In addition, the flight profile alleviation factor already defined for the discrete gust in § 25.341(a) as amended (Amendment 25-86, 61 FR 5218, February 9, 1996) would be used to adjust the gust intensity distribution according to certain aircraft parameters that relate to the intended use of the airplane. The FAA considers this to be a reliable means of accounting for airplane mission and it would be capable of being applied in a uniform manner.

One member of the ARAC Working Group objected to the definition of a flight profile alleviation factor that changes the design turbulence intensity versus altitude based on selected aircraft design parameters. That member believed that the once in 70,000 hour gust represented an acceptable level of turbulence for design purposes. He accepted that the intensity of the 70,000 hour gust properly varies with altitude; but he believed the probability of encountering a gust of that intensity at any point in time should be constant, regardless of the design parameters of a particular aircraft.

The majority of the ARAC Working Group disagreed. In their view the proposal does not assume that atmospheric turbulence is dependent upon aircraft speed and altitude, or any other aircraft design parameter. The flight profile alleviation factor is simply a mathematical device that allows the expected operation of the airplane to be taken into account by introducing multiplying factors, based on fuel loading and maximum operating altitude, that adjust the required design turbulence intensities. The flight profile alleviation factor in this proposal is identical in magnitude and effect to that used in the discrete gust requirements of § 25.341(a) (as amended by Amendment 25-86, 61 FR 5218, February 9, 1996). To support this proposal, an effort has been undertaken by the industries and airworthiness authorities of the United States, Canada and Europe to evaluate the new proposed criteria and ensure that they are adequate for current conventional transport airplanes as well as for new technology airplanes that may include systems that react in a non-linear manner. Furthermore, the proposed design turbulence intensity distributions are believed to represent the best available measurements of the turbulence environment in which the airplane is likely to be operated.

The mission analysis method for accounting for continuous turbulence loads would be eliminated as an option since the use of this method can provide inconsistent results depending on the assumptions made concerning the potential use of the airplane. The elimination of this method would not be significant since few manufacturers currently use it as the primary means of addressing continuous turbulence. In addition, the mission would be taken into account in the proposed design envelope criterion, since a flight profile alleviation factor is provided as discussed above.

The introduction of advanced flight control systems into transport airplanes has presented special problems in the treatment of continuous turbulence. Some of these systems can exhibit significant non-linearities, while the standard mathematical approaches to continuous turbulence (i.e. frequency domain solutions) are valid only for linear systems. The current rule requires consideration of non-linearities only in relation to stability augmentation systems, however, with modern transport airplanes it is possible that the primary flight control systems and the airplane itself could exhibit significant non-linearities. The proposed rule would require that any significant non-linearity be considered in a realistic or conservative manner, and it would provide additional criteria which can be used with other rational approaches that can account for non-linearities (e.g. time domain solutions).

The elimination of the mission analysis criterion would simplify the presentation of the continuous turbulence requirement so that the requirement can be conveniently presented directly in Subpart C rather than in Appendix G. Appendix G would be eliminated and the continuous turbulence requirement would be set forth, with some reorganization and clarification, in paragraph (b) of § 25.341 "Gust and turbulence loads".

Following an accident in which an airplane shed a large wing mounted nacelle, the National Transportation Safety Board (NTSB) recommended (Safety Recommendation A-93-137, November 15, 1993) that the FAA should amend the design load requirements to consider multiple axis loads encountered during severe turbulence. This recommendation was specifically addressed at gust loads on wing-mounted engines. Although the FAA believes that the existing designs are adequate and that the existing gust criteria have already been improved to the point that they should be adequate for current and future configurations, there remains a possibility that a multi-axis gust encounter could produce higher loads under certain situations. To address the NTSB concern, the FAA contracted an independent organization to develop a method of performing multiaxis discrete gust analysis for wing mounted nacelles. The results of that study were reported to FAA in Stirling Dynamics Labratories Report No SDL –571-TR-2 dated May 1999. The recommendations of that report were accepted by ARAC and the FAA and are set forth in this proposal. The proposal addresses the NTSB recommendation by prescribing two dynamic gust criteria for airplanes with wing mounted engines. These are a round-the-clock discrete gust criterion and a multi-axis dual discrete gust criterion. These criteria are set forth in a new paragraph 25.341(c). The current § 25.445 already requires the effects of combined gust loading to be considered on auxiliary aerodynamic surfaces such as outboard fins and winglets. Furthermore, the current § 25.427(c) requires the effects of combined gust loading to be considered on some empennage arrangements such as T-tails. For airplanes with wing mounted engines, this proposal would extend the round the clock dynamic discrete gust criterion to wing mounted nacelles and provide an additional multi-axis dynamic discrete gust criterion. These criteria, set forth in § 25.341(c), would be applied as airplane dynamic conditions although the assessment would be limited to the engine mounts, pylons and wing supporting structure.

Section 25.571, "Damage tolerance and fatigue evaluation of structure", currently references the entire section 25.341 as one source of residual strength loads for the damage tolerance assessment. No changes are proposed for this reference to § 25.341, so the additional gust loads derived from the new § 25.341(c) would be included in the damage tolerance assessment required by § 25.571.

Some current part 25 airplanes have maximum certified operating altitudes up to 51,000 feet. To be fully applicable to these, and future part 25 airplanes, this proposal defines gust intensities for all altitudes up to 60,000 feet. This is inconsistent with the discrete gust requirements of § 25.341(a) (as amended by Amendment 25-86, 61 FR 5218, February 9, 1996), that define the discrete gust velocities at altitudes up to 50,000 feet only. Therefore, as a conforming change, it is proposed to amend § 25.341(a)(5)(i) to define discrete gust velocities up to 60,000 feet, thereby achieving consistency between discrete gust and continuous turbulence criteria.

With the adoption of the discrete gust in § 25.341(a) as amended (Amendment 25-86, 61 FR 5218, February 9, 1996), paragraph 25.343 "Design fuel and oil loads" was amended as a conforming change so that the design criterion for the structural reserve fuel condition included only the discrete gust of paragraph 25.341(a) and not the continuous turbulence of 25.341(b). However, the FAA believes that both a continuous turbulence criterion and a discrete gust criterion are needed since they account for the response to totally different, but still realistic, atmospheric characteristics. Therefore, to meet the level of safety intended by the structural reserve fuel requirements it was deemed necessary to include a continuous turbulence loads criterion in paragraph (b)(1)(ii) of § 25.343.

With the adoption of the discrete gust in § 25.341(a) as amended (Amendment 25-86, 61 FR 5218, February 9, 1996), paragraph 25.345 "High lift devices" was amended as a conforming change so that the design criterion for en-route conditions with flaps deployed included only the discrete gust of paragraph 25.341(a) and not the continuous turbulence of 25.341(b). However, the FAA believes that both a continuous turbulence criterion and a discrete gust criterion are needed since they account for the response to totally different, but still realistic, atmospheric characteristics. Therefore, to meet the level of safety intended by the en-route requirements it was deemed necessary to include a continuous turbulence loads criterion in paragraph (c)(2) of § 25.345.

With the adoption of the discrete gust in § 25.341(a) as amended (Amendment 25-86, 61 FR 5218, February 9, 1996), paragraph 25.371 "Gyroscopic loads" was amended as a conforming change so that gyroscopic loads were associated only with the discrete gust of paragraph 25.341(a) and not the continuous turbulence of 25.341(b). However, the FAA believes that in order to meet the level of safety intended by the revised continuous turbulence requirements it will be necessary to include gyroscopic effects, where appropriate, in calculation of total loads due to continuous turbulence. To this end a change is proposed to Section 25.371 so that it would reference the entire section 25.341 and include both continuous turbulence loads as well as discrete gust loads.

With the adoption of the discrete gust in § 25.341(a) as amended (Amendment 25-86, 61 FR 5218, February 9, 1996), paragraph 25.373 "Speed Control Devices" was amended as a conforming change so that the design requirement for these devices referenced only the discrete gust of paragraph 25.341(a) and not the continuous turbulence of 25.341(b). The continuous turbulence paragraph was moved from 25.305(d) to 25.341(b) only as an organizational change, and in order to not impose additional requirements on speed control devices, such as speed brakes, it was necessary to change the reference so that it only referred to 25.341(a). Now, however, FAA believes that encounters with continuous turbulence can result in the activation of speed brakes to slow the airplane to the recommended turbulence penetration speeds, and so the loads induced by turbulence should be considered while these devices are deployed. To this end, a change is proposed to Section 25.373 so that it would reference the entire section 25.341 and include both continuous turbulence loads as well as discrete gust loads.

With the adoption of the discrete gust in § 25.341(a) as amended (Amendment 25-86, 61 FR 5218, February 9, 1996), paragraph 25.391 "Control surface loads: general" was amended as a conforming change so that the design load criterion for control surfaces included only the discrete gust of paragraph 25.341(a) and not the continuous turbulence of 25.341(b). However, the FAA believes that both a continuous turbulence criterion and a discrete gust criterion are needed since they account for the response to totally different, but still realistic, atmospheric characteristics. Therefore, to meet the level of safety intended for the aircraft as a whole it was deemed necessary to design control surfaces for limit loads resulting from the continuous turbulence conditions. To this end a change is proposed to Section 25.391 so that it would include 25.341(a) and 25.341(b) for discrete gust as well as continuous turbulence loads.

The proposal does not include a continuous turbulence design condition at V_B, "the design speed for maximum gust intensity". The design turbulence intensities established for the gust design conditions at V_C, "structural design cruising speed," and V_D, "structural design diving speed," were developed in consideration of the full operational envelope so that a specific continuous turbulence design condition at V_B is not considered necessary, provided the current practices for operating in severe turbulence are continued. Since Amendment 25-86 (61 FR 5221, February 9, 1996) the discrete gust requirements of § 25.341 have not contained a specific discrete gust design condition at V_B. Without any specific discrete gust or continuous turbulence design criteria at V_B there is no technical reason to prescribe a rough air speed based upon V_B. Therefore, it is proposed to amend § 25.1517 to remove the link between V_{RA} and V_B.

Paperwork Reduction

In accordance with the Paperwork Reduction Act of 1995 (44 U.S.C. 3507(d)), there are no requirements for information collection associated with this proposed rule.

International Compatibility

The FAA reviewed the corresponding International Civil Aviation Organization regulations, where they exist, and has identified no differences in these proposed amendments and the foreign regulations. The FAA has also reviewed the Joint Airworthiness Authorities Regulations and has discussed similarities and differences in these proposed amendments and the foreign regulations.

Regulatory Evaluation Summary

Preliminary Regulatory Evaluation, Initial Regulatory Flexibility Determination, and Trade Impact Assessment

Proposed changes to Federal regulations must undergo several economic analyses. First, Executive Order 12866 directs that each Federal agency shall propose or adopt a regulation only upon a reasoned determination that the benefits of the intended regulation justify its costs. Second, the Regulatory Flexibility Act of 1980 requires agencies to analyze the economic effect of regulatory changes on small entities. Third, the Office of Management and Budget directs agencies to assess the effects of regulatory changes on international trade. In conducting these analyses, the FAA has determined that this rule: (1) would generate benefits that justify its costs and is not a "significant regulatory action" as defined in the Executive Order; (2) is not significant as defined in DOT's Regulatory Policies and Procedures; (3) would not have a significant impact on a substantial number of small entities; and (4) would not constitute a barrier to international trade. These analyses, available in the docket, are summarized below.

Regulatory Evaluation Summary

[To be completed]

Regulatory Flexibility Determination

The Regulatory Flexibility Act of 1980 (RFA) was enacted by Congress to ensure that small entities are not unnecessarily and disproportionally burdened by Federal regulations. The

RFA requires agencies to determine whether rules would have "a significant economic impact on a substantial number of small entities," and, in cases where they would, to conduct a regulatory flexibility analysis. " FAA Order 2100.1 4A, Regulatory Flexibility Criteria and Guidance, prescribes standards for complying with RFA requirements in FAA rulemaking actions. The Order defines "small entities" in terms of size thresholds, "significant economic impact" in terms of annualized cost thresholds, and "substantial number" as a number which is not less than eleven and which is more than one-third of the affected small entities.

The proposed rule would affect manufacturers of transport category airplanes produced under future new airplane type certifications. For airplane manufacturers, FAA Order 2100.14A specifies a size threshold for classification as a small entity as 75 or fewer employees. Since no part 25 airplane manufacturer has 75 or fewer employees, the proposed rule would not have a significant economic impact on a substantial number of small airplane manufacturers.

International Trade Impact Assessment

The proposed rule would have no adverse impact on trade opportunities for U.S. manufacturers selling airplanes in foreign markets and foreign manufacturers selling airplanes in the U.S. market. Instead, by harmonizing the standards of the FAR and the JAR, it would lessen restraints on trade.

Federalism Implications

The regulations proposed herein would not have substantial direct effects on the states, on the relationship between the national government and the states, or on the distribution of power and responsibilities among the various levels of government. Thus, in accordance with Executive Order 12612, it is determined that this proposal does not have sufficient federalism implications to warrant the preparation of a Federalism Assessment.

Conclusion

Because the proposed changes to the continuous turbulence design load requirement are not expected to result in any substantial economic costs, the FAA has determined that this proposed regulation would not be significant under Executive Order 12866. Because this is an issue that has not prompted a great deal of public concern, the FAA has determined that this action is not significant under DOT Regulatory Policies and Procedures (44 FR 11034; February 25, 1979). In addition, since there are no small entities affected by this rulemaking, the FAA certifies that the rule, if promulgated, would not have a significant economic impact, positive or negative, on a substantial number of small entities under the criteria of the Regulatory Flexibility Act, since none would be affected. A copy of the regulatory evaluation prepared for this project may be examined in the Rules Docket or obtained from the person identified under the caption "FOR FURTHER INFORMATION CONTACT."

List of Subjects in 14 CFR part 25

Air transportation, Aircraft, Aviation safety, Safety.

The Proposed Amendments

Accordingly, the Federal Aviation Administration (FAA) proposes to amend 14 CFR part 25 of the Federal Aviation Regulations (FAR) as follows:

PART 25 - AIRWORTHINESS STANDARDS: TRANSPORT CATEGORY AIRPLANES

1. The authority citation for Part 25 continues to read as follows:

Authority: 49 U.S.C. app. 1347, 1348, 1354(a), 1357 (d)(2), 1372, 1421 through 1430, 1432, 1442, 1443, 1472, 1510, 1522, 1652(e), 1655(c), 1657(f), 49 U.S.C. 106(g)

2. By removing Appendix G to part 25, "Continuous Gust Design Criteria" and marking it "Reserved".

3. To amend Section 25.341 by revising paragraph 25.341(a)(5)(i) to read as follows:

(a) * * * * *

(5) The following reference gust velocities apply:

(i) At airplane speeds between V_B and V_C:

Positive and negative gusts with reference gust velocities of 56.0 ft/sec EAS must be considered at sea level. The reference gust velocity may be reduced linearly from 56·0 ft/sec EAS at sea level to 44.0 ft/sec EAS at 15 000 feet. The reference gust velocity may be further reduced linearly from 44.0 ft/sec EAS at 15 000 feet to 20.86 ft/sec EAS at 60 000 feet.

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4. To amend Section 25.341 by revising paragraph 25.341(b) and adding a new paragraph 25.341(c) to read as follows:

(b) *Continuous Turbulence Design Criteria.* The dynamic response of the airplane to vertical and lateral continuous turbulence must be taken into account. The dynamic analysis must take into account unsteady aerodynamic characteristics and all significant structural degrees of freedom including rigid body motions. The limit loads must be determined for all critical altitudes, weights, and weight distributions as specified in § 25.321(b), and all critical speeds within the ranges indicated in paragraph (b)(3).

(1) Except as provided in paragraphs (b)(4) and (b)(5) of this section, the following equation must be used:

$$P_L = P_{L\text{-}1g} \pm U_\sigma \overline{A}$$

Where——

P_L = limit load;

$P_{L\text{-}1g}$ = steady 1-g load for the condition;

$\overline{A}$ = ratio of root-mean-square incremental load for the condition to root-mean-square turbulence velocity; and

U_σ = limit turbulence intensity in true airspeed, specified in paragraph (b)(3) of this section.

(2) Values of $\overline{A}$ must be determined according to the following formula:

$$\overline{A} = \sqrt{\int_0^\infty |H(\Omega)|^2 \Phi(\Omega) d\Omega}$$

Where——

$H(\Omega)$ = the frequency response function, determined by dynamic analysis, that relates the loads in the aircraft structure to the atmospheric turbulence; and

$\Phi(\Omega)$ = normalized power spectral density of atmospheric turbulence given by——

$$\Phi(\Omega) = \frac{L}{\pi} \frac{1 + \frac{8}{3}(1.339L\Omega)^2}{\left[1 + (1.339L\Omega)^2\right]^{11/6}}$$

Where——

Ω = reduced frequency, radians per foot.; and

L = scale of turbulence = 2,500 ft.

(3) The limit turbulence intensities, U_σ, in feet per second true airspeed required for compliance with this paragraph are——

(i) At airplane speeds between V_B and V_C:

$U_\sigma = U_{\sigma ref} F_g$

Where—

$U_{\sigma ref}$ is the reference turbulence intensity that varies linearly with altitude from 90 fps (TAS) at sea level to 79 fps (TAS) at 24000 feet and is then constant at 79 fps (TAS) up to the altitude of 60000 feet.

F_g is the flight profile alleviation factor defined in paragraph (a)(6) of this section;

(ii) At speed V_D: $U\sigma$ is equal to 1/2 the values obtained under subparagraph (3)(i) of this paragraph.

(iii) At speeds between V_C and V_D: $U\sigma$ is equal to a value obtained by linear interpolation.

(iv) At all speeds both positive and negative continuous turbulence must be considered.

(4) When an automatic system affecting the dynamic response of the airplane is included in the analysis, the effects of system non-linearities on loads at the limit load level must be taken into account in a realistic or conservative manner.

(5) If necessary for the assessment of loads on airplanes with significant non-linearities, it must be assumed that the turbulence field has a root-mean-square velocity equal to 40 percent of the U_σ values specified in subparagraph (3). The value of limit load is that load with the same probability of exceedance in the turbulence field as $\bar{A} U_\sigma$ of the same load quantity in a linear approximated model.

(c) *Supplementary gust conditions for wing mounted engines*. For airplanes equipped with wing mounted engines, the engine mounts, pylons, and wing supporting structure must be designed for the maximum response at the nacelle center of gravity derived from the following dynamic gust conditions applied to the airplane:

(1) A discrete gust determined in accordance with 25.341(a) at each angle normal to the flight path, and separately,

(2) A pair of discrete gusts, one vertical and one lateral. The length of each of these gusts must be independently tuned to the maximum response in accordance with 25.341(a). The penetration of the airplane in the combined gust field and the phasing of the vertical and lateral component gusts must be established to develop the maximum response to the gust pair. In the

absence of a more rational analysis, the following formula must be used for each of the maximum engine loads in all six degrees of freedom:

$$P_L = P_{L-1g} + 0.85\sqrt{L_V^2 + L_L^2}$$

Where—

P_L = limit load;

P_{L-1g} = steady 1-g load for the condition;

L_V = Peak incremental response load due to a vertical gust according to § 25.341(a); and

L_L = Peak incremental response load due to a lateral gust according to § 25.341(a).

5. To amend Section 25.343 by revising paragraph 25.343(b)(1)(ii) to read as follows:

(b) * * * * *

(1) * * * * *

(ii) The gust and turbulence conditions of § 25.341, but assuming 85% of the gust velocities prescribed in § 25.341(a)(4) and 85% of the turbulence intensities prescribed in § 25.341(b)(3).

6. To amend Section 25.345 by revising paragraph 25.345(c)(2) to read as follows:

(c) * * * * *

(2) The vertical gust and turbulence conditions prescribed in § 25.341.

7. To amend Section 25.371 to read as follows:

§ 25.371 Gyroscopic loads.

The structure supporting any engine or auxiliary power unit must be designed for the loads, including gyroscopic loads, arising from the conditions specified in §§ 25.331, 25.341, 25.349, 25.351, 25.473, 25.479, and 25.481, with the engine or auxiliary power unit at the maximum rpm appropriate to the condition. For the purposes of compliance with this paragraph, the pitch maneuver in § 25.331(c)(1) must be carried out until the positive limit maneuvering load factor (point A_2 in § 25.333(b)) is reached.

9. To amend Section 25.373 by revising paragraph 25.373(a) to read as follows:

(a) The airplane must be designed for the symmetrical maneuvers and gusts prescribed in §§ 25.333, 25.337, the yawing maneuvers in §25.351, and the vertical and lateral gust and turbulence conditions prescribed in § 25.341(a) and (b) at each setting and the maximum speed associated with that setting; and;

* * * * *

10. To amend Section 25.391 to read as follows:

§ 25.391 Control surface loads: general

The control surfaces must be designed for the limit loads resulting from the flight conditions in §§ 25.331, 25.341(a) and (b), 25.349 and 25.351 and the ground gust conditions in § 25.415, considering the requirements for------

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11. To amend Section 25.1517 to read as follows:

§ 25.1517 Rough air speed V_{RA}

(a) At altitudes where V_{MO} is not limited by Mach number, a rough air speed V_{RA}, for use as the recommended turbulence penetration air speed, must be established which:

1) is not less than a speed allowing a positive maneuvering load factor of 1.4 before the onset of perceptible buffeting.

2) is sufficiently less than the maximum operating speed to ensure that likely speed variation during rough air encounters will not cause the overspeed warning to operate too frequently.

In the absence of a rational investigation substantiating the use of other values, V_{RA} must be less than V_{MO}-35 KTAS.

(b) At altitudes where V_{MO} is limited by Mach number, a rough air Mach number M_{RA}, for use as the recommended turbulence penetration Mach number, may be chosen to provide an optimum margin between low and high speed buffet boundaries."

Issued in Washington D.C. on

U.S. Department
of Transportation
Federal Aviation
Administration

Subject: DYNAMIC GUST LOADS	Date: 9/22/99 Initiated by: ANM-110	AC No. 25.341-1 Change:

1. PURPOSE. This advisory circular (AC) sets forth an acceptable means of compliance with the provisions of FAR Part 25 of the Federal Aviation Regulations (FAR) dealing with discrete gust and continuous turbulence dynamic loads.

2. RELATED FAR SECTIONS. The contents of this AC are considered by the FAA in determining compliance with the discrete gust and continuous turbulence criteria defined in Paragraph 25.341. Related sections are:

25.343	Design fuel and oil loads
25.345	High lift devices
25.349	Rolling conditions
25.371	Gyroscopic loads
25.373	Speed control devices
25.391	Control surface loads
25.427	Unsymmetrical loads
25 445	Auxiliary aerodynamic surfaces
25.571	Damage-tolerance and fatigue evaluation of structure

Reference should also be made to Paragraphs, 25.301, 25.302, 25.303, 25.305, 25.321, 25.335, 25.1517.

3. OVERVIEW. This AC addresses both discrete gust and continuous turbulence (or continuous gust) requirements of FAR Part 25. It provides some of the acceptable methods of modeling airplanes, airplane components, and configurations, and the validation of those modeling methods for the purpose of determining the response of the airplane to encounters with gusts.

How the various airplane modeling parameters are treated in the dynamic analysis can have a large influence on design load levels. The basic elements to be modeled in the analysis are the elastic, inertial, aerodynamic and control system characteristics of the complete, coupled airplane (Figure 1). The degree of sophistication and detail required in the modeling depends on the complexity of the airplane and its systems.

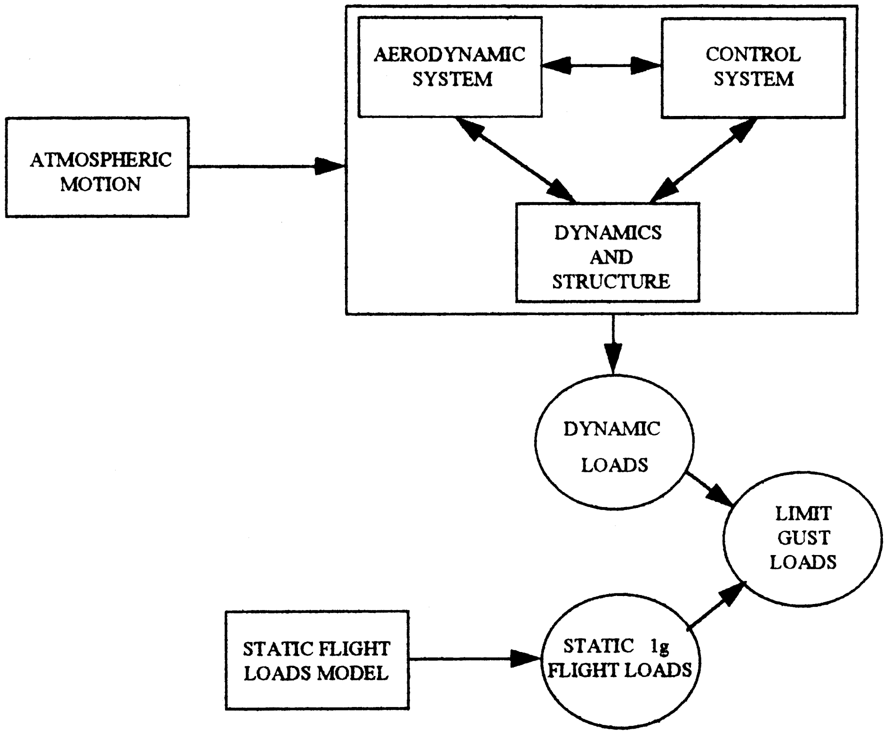

Figure 1 Basic Elements of the Gust Response Analysis

Design loads for encounters with gusts are a combination of the steady level 1-g flight loads, and the gust incremental loads including the dynamic response of the airplane. The steady 1-g flight loads can be realistically defined by the basic external parameters such as speed, altitude, weight and fuel load. They can be determined using static aeroelastic methods.

The gust incremental loads result from the interaction of atmospheric turbulence and airplane rigid body and elastic motions. They may be calculated using linear analysis methods when the airplane and its flight control systems are reasonably or conservatively approximated by linear analysis models.

Nonlinear solution methods are necessary for airplane and flight control systems that are not reasonably or conservatively represented by linear analysis models. Nonlinear features generally raise the level of complexity, particularly for the continuous turbulence analysis, because they often require that the solutions be carried out in the time domain.

The modeling parameters discussed in the following sections include:

- Design conditions and associated steady, level 1-g flight conditions.
- The discrete and continuous gust models of atmospheric turbulence.
- Detailed representation of the airplane system including structural dynamics, aerodynamics, and control system modeling.

- Solution of the equations of motion and the extraction of response loads.
- Considerations for nonlinear airplane systems.
- Analytical model validation techniques.

4. DESIGN CONDITIONS.

a. General. Analyses should be conducted to determine gust response loads for the airplane throughout its design envelope, where the design envelope is taken to include, for example, all appropriate combinations of airplane configuration, weight, center of gravity, payload, fuel load, thrust, speed, and altitude.

b. Steady Level 1-g Flight Loads. The total design load is made up of static and dynamic load components. In calculating the static component, the airplane is assumed to be in trimmed steady level flight, either as the initial condition for the discrete gust evaluation or as the mean flight condition for the continuous turbulence evaluation. Static aeroelastic effects should be taken into account if significant.

To ensure that the maximum total load on each part of the airplane is obtained, the associated steady-state conditions should be chosen in such a way as to reasonably envelope the range of possible steady-state conditions that could be achieved in that flight condition. Typically, this would include consideration of effects such as speed brakes, power settings between zero thrust and the maximum for the flight condition, etc.

c. Dynamic Response Loads. The incremental loads from the dynamic gust solution are superimposed on the associated steady level flight 1-g loads. Load responses in both positive and negative senses should be assumed in calculating total gust response loads. Generally the effects of speed brakes, flaps, or other drag or high lift devices, while they should be included in the steady-state condition, may be neglected in the calculation of incremental loads.

d. Damage Tolerance Conditions. Limit gust loads, treated as ultimate, need to be developed for the structural failure conditions considered under Paragraph 25.571(b). Generally, for redundant structures, significant changes in stiffness or geometry do not occur for the types of damage under consideration. As a result, the limit gust load values obtained for the undamaged aircraft may be used and applied to the failed structure. However, when structural failures of the types considered under Paragraph 25.571(b) cause significant changes in stiffness or geometry, or both, these changes should be taken into account when calculating limit gust loads for the damaged structure.

5. GUST MODEL CONSIDERATIONS.

a. General. The gust criteria presented in Paragraph 25.341 consist of two models of atmospheric turbulence, a discrete model and a continuous turbulence model. It is beyond the scope of this AC to review the historical development of these models and their associated parameters. This information can be found in the preamble to FAR Part 25. This AC focuses on the application of those gust criteria to establish design limit loads. The discrete gust model is used to represent single discrete extreme turbulence events. The continuous turbulence model represents longer duration turbulence encounters which excite lightly damped modes. Dynamic loads for both atmospheric models must be considered in the structural design of the airplane.

b. Discrete Gust Model

(1) Atmosphere. The atmosphere is assumed to be one dimensional with the gust velocity acting normal (either vertically or laterally) to the direction of airplane travel. The one-dimensional assumption constrains the instantaneous vertical or lateral gust velocities to be the same at all points in planes normal to the direction of airplane travel. Design level discrete gusts are assumed to have 1-cosine velocity profiles. The maximum velocity for a discrete gust is calculated using a reference gust velocity, U_{REF}, a flight profile alleviation factor, F_g, and an expression which modifies the maximum velocity as a function of the gust gradient distance, H. These parameters are discussed further below.

(A) Reference Gust Velocity, U_{REF} - Derived effective gust velocities representing gusts occurring once in 70,000 flight hours are the basis for design gust velocities. These reference velocities are specified as a function of altitude in Paragraph 25.341(a)(5) and are given in terms of feet per second equivalent airspeed for a gust gradient distance, H, of 350 feet.

(B) Flight Profile Alleviation Factor, F_g - The reference gust velocity, U_{REF}, is a measure of turbulence intensity as a function of altitude. In defining the value of U_{ref} at each altitude, it is assumed that the aircraft is flown 100% of the time at that altitude. The factor F_g is then applied to account for the expected service experience in terms of the probability of the airplane flying at any given altitude within its certification altitude range. F_g is a minimum value at sea level, linearly increasing to 1.0 at the certified maximum altitude. The expression for F_g is given in Paragraph 25.341(a)(6).

(C) Gust Gradient Distance, H - The gust gradient distance is that distance over which the gust velocity increases to a maximum value. Its value is specified as ranging from 30 to 350 ft. (It should be noted that if 12.5 times the mean geometric chord of the airplane's wing exceeds 350 feet, consideration should be given to covering increased maximum gust gradient distances.)

(D) Design Gust Velocity, U_{ds} - Maximum velocities for design gusts are proportional to the sixth root of the gust gradient distance, H. The maximum gust velocity for a given gust is then defined as:

$$U_{ds} = U_{REF}\, F_g\, (H/350)^{(1/6)}$$

The maximum design gust velocity envelope, U_{ds}, and example design gust velocity profiles are illustrated in Figure 2.

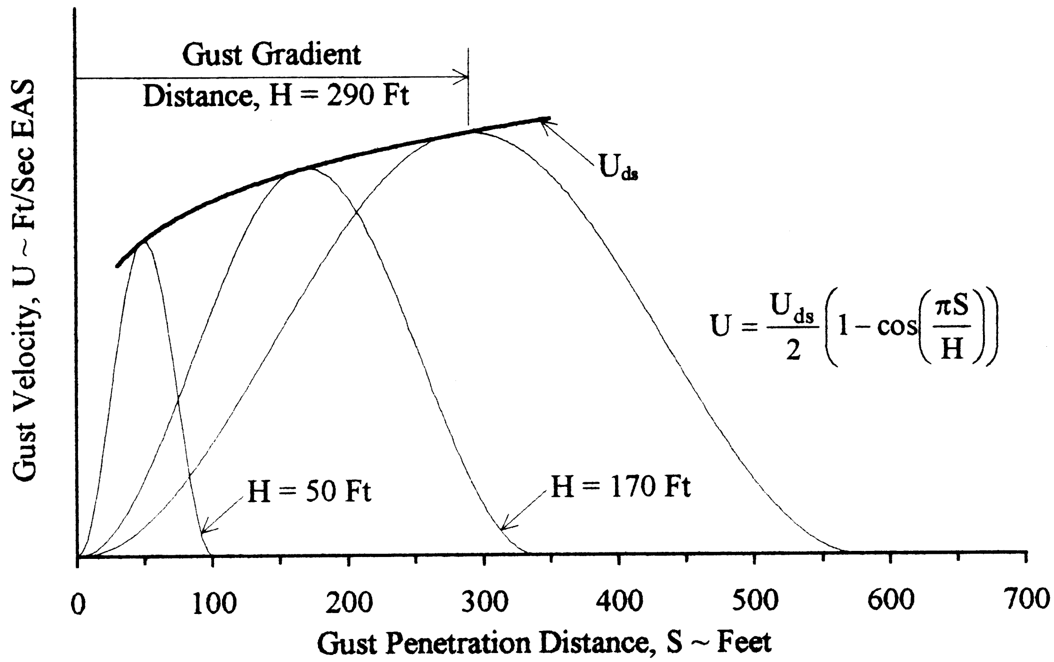

Figure-2 Typical (1-cosine) Design Gust Velocity Profiles

(2) Discrete Gust Response. The solution for discrete gust response time histories can be achieved by a number of techniques. These include the explicit integration of the airplane equations of motion in the time domain, and frequency domain solutions utilizing Fourier transform techniques. These are discussed further in Section 7.0 of this AC.

Maximum incremental loads, P_{Ii} , are identified by the peak values selected from time histories arising from a series of separate, 1-cosine shaped gusts having gradient distances ranging from 30 to 350 feet. Input gust profiles should cover this gradient distance range in sufficiently small increments to determine peak loads and responses. Historically 10 to 20 gradient distances have been found to be acceptable. Both positive and negative gust velocities should be assumed in calculating total gust response loads. It should be noted that in some cases, the peak incremental loads can occur well after the prescribed gust velocity has returned to zero. In such cases, the gust response calculation should be run for sufficient additional time to ensure that the critical incremental loads are achieved.

The design limit load, P_{Li}, corresponding to the maximum incremental load, P_{Ii} for a given load quantity is then defined as:

$$P_{Li} = P_{(1\text{-}g)i} \pm P_{Ii}$$

Where $P_{(1\text{-}g)i}$ is the 1-g steady load for the load quantity under consideration. The set of time correlated design loads, P_{Lj}, corresponding to the peak value of the load quantity, P_{Li}, are calculated for the same instant in time using the expression:

$$P_{Lj} = P_{(1\text{-}g)j} \pm P_{Ij}$$

Note that in the case of a nonlinear aircraft, maximum positive incremental loads may differ from maximum negative incremental loads.

When calculating stresses which depend on a combination of external loads it may be necessary to consider time correlated load sets at time instants other than those which result in peaks for individual external load quantities.

(3) Round-The-Clock Gust. When the effect of combined vertical and lateral gusts on airplane components is significant, then round-the-clock analysis should be conducted on these components and supporting structures. The vertical and lateral components of the gust are assumed to have the same gust gradient distance, H and to start at the same time. Components that should be considered include horizontal tail surfaces having appreciable dihedral or anhedral (i.e., greater than 10°), or components supported by other lifting surfaces, for example T-tails, outboard fins and winglets. While the round-the-clock load assessment may be limited to just the components under consideration, the loads themselves should be calculated from a whole airplane dynamic analysis.

The round-the-clock gust model assumes that discrete gusts may act at any angle normal to the flight path of the airplane. Lateral and vertical gust components are correlated since the round-the-clock gust is a single discrete event. For a linear airplane system, the loads due to a gust applied from a direction intermediate to the vertical and lateral directions - the round-the-clock gust loads - can be obtained using a linear combination of the load time histories induced from pure vertical and pure lateral gusts. The resultant incremental design value for a particular load of interest is obtained by determining the round-the-clock gust angle and gust length giving the largest (tuned) response value for that load. The design limit load is then obtained using the expression for P_L given above in section 5.b.2.

(4) Supplementary Gust Conditons for Wing Mounted Engines.

(A) Atmosphere - For aircraft equipped with wing mounted engines, FAR paragraph 25.341(c) requires that engine mounts, pylons and wing supporting structure be designed to meet a round-the-clock discrete gust requirement and a multi-axis discrete gust requirement.

The model of the atmosphere and the method for calculating response loads for the round-the-clock gust requirement is the same as that described in Section 5(b)(3) of this AC.

For the multi-axis gust requirement, the model of the atmosphere consists of two independent discrete gust components, one vertical and one lateral, having amplitudes such that the overall probability of the combined gust pair is the same as that of a single discrete gust as defined by FAR paragraph 25.341(a) as described in Section 5(b)(1) of this AC. To achieve this equal-probability condition, in addition to the reductions in gust amplitudes that would be applicable if the input were a multi-axis Gaussian process, a further factor of 0.85 is incorporated into the gust amplitudes to account for non-Gaussian properties of severe discrete gusts. This factor was derived from severe gust data obtained by a research aircraft specially instrumented to measure vertical and lateral gust components. This information is contained in Stirling Dynamics Labratories Report No SDL –571-TR-2 dated May 1999.

(B) Multi-Axis Gust Response - For a particular aircraft flight condition, the calculation of a specific response load requires that the amplitudes, and the time phasing, of the two gust components be chosen, subject to the condition on overall probability specified in (A) above, such that the resulting combined load is maximized. For loads calculated using a linear aircraft model, the response load may be based upon the separately tuned vertical and lateral discrete gust responses for that load, each calculated as described in Section 5(b)(2) of this AC. In general, the vertical and lateral tuned gust lengths and the times to maximum response (measured from the onset of each gust) will not be the same.

Denote the independently tuned vertical and lateral incremental responses for a particular aircraft flight condition and load quantity i by L_{Vi} and L_{Li}, respectively.The associated multi-axis gust input is obtained by multiplying the amplitudes of the independently-tuned vertical and lateral discrete gusts, obtained as described in the previous paragraph, by $0.85*L_{Vi}/\sqrt{(L_{Vi}^2+L_{Li}^2)}$ and $0.85*L_{Li}/\sqrt{(L_{Vi}^2+L_{Li}^2)}$ respectively. The time-phasing of the two scaled gust components is such that their associated peak loads occur at the same instant.

The combined incremental response load is given by:

$$P_{Ii} = 0.85\sqrt{(L_{Vi}^2+L_{Li}^2)}$$

and the design limit load, P_{Li}, corresponding to the maximum incremental load, P_{Ii}, for the given load quantity is then given by:

$$P_{Li} = P_{(1\text{-}g)i} \pm P_{Ii}$$

where $P_{(1\text{-}g)i}$ is the 1-g steady load for the load quantity under consideration.

The incremental, time correlated loads corresponding to the specific flight condition under consideration are obtained from the independently-tuned vertical and lateral gust inputs for load quantity i. The vertical and lateral gust amplitudes are factored by $0.85*L_{Vi}/\sqrt{(L_{Vi}^2+L_{Li}^2)}$ and $0.85*L_{Li}/\sqrt{(L_{Vi}^2+L_{Li}^2)}$ respectively. Loads L_{Vj} and L_{Lj} resulting from these reduced vertical and lateral gust inputs, at the time when the amplitude of load quantity i is at a maximum value, are added to yield the multi-axis incremental time-correlated value P_{Ij} for load quantity j.

The set of time correlated design loads, P_{Lj}, corresponding to the peak value of the load quantity, P_{Li}, are obtained using the expression:

$$P_{Lj} = P_{(1\text{-}g)j} \pm P_{Ij}$$

Note that with significant nonlinearities, maximum positive incremental loads may differ from maximum negative incremental loads.

c. Continuous Turbulence Model.

(1) Atmosphere. The atmosphere for the determination of continuous gust responses is assumed to be one dimensional with the gust velocity acting normal (either vertically or laterally) to the direction of airplane travel. The one-dimensional assumption constrains the instantaneous vertical or lateral gust velocities to be the same at all points in planes normal to the direction of airplane travel.

The random atmosphere is assumed to have a Gaussian distribution of gust velocity intensities and a von Karman power spectral density with a scale of turbulence, L, equal to 2500 feet. The expression for the von Karman spectrum for unit, root-mean-square (RMS) gust intensity, $\Phi_I(\Omega)$, is given below. In this expression $\Omega = \omega/V$ where, ω is the circular frequency in radians per second, and V is the airplane velocity in feet per second true airspeed.

$$\Phi_I(\Omega) = \frac{L}{\pi} \frac{1+\frac{8}{3}(1.339\Omega L)^2}{[1+(1.339\Omega L)^2]^{11/6}}$$

The von Karman power spectrum for unit RMS gust intensity is illustrated in Figure 3.

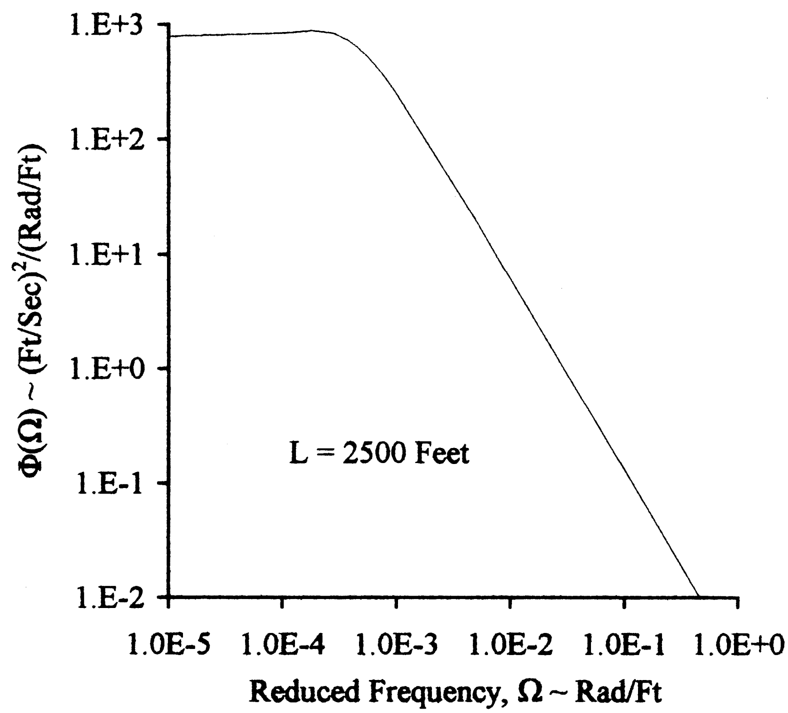

Figure-3 The von Karman Power Spectral Density Function, $\Phi_I(\Omega)$

The design gust velocity, U_σ, applied in the analysis is given by the product of the reference gust velocity, $U_{\sigma REF}$, and the profile alleviation factor, F_g, as follows:

$$U_\sigma = U_{\sigma REF} F_g$$

where values for $U_{\sigma REF}$, are specified in Paragraph 25.341(b)(3) in feet per second true airspeed and F_g is defined in Paragraph 25.341(a)(6). The value of F_g is based on airplane design parameters and is a minimum value at sea level, linearly increasing to 1.0 at the certified maximum design altitude. It is identical to that used in the discrete gust analysis.

As for the discrete gust analysis, the reference continuous turbulence gust intensity, $U_{\sigma REF}$, defines the design value of the associated gust field at each altitude. In defining the value of $U_{\sigma REF}$ at each altitude, it is assumed that the airplane is flown 100% of the time at that altitude. The factor F_g is then applied to account for the probability of the airplane flying at any given altitude during its service lifetime.

It should be noted that the reference gust velocity is comprised of two components, a root-mean-square (RMS) gust intensity and a peak to RMS ratio. The separation of these components is not defined and is not required for the linear airplane analysis. Guidance is provided in Section 8.d. of this AC for generating a RMS gust intensity for a nonlinear simulation.

(2) Continuous Turbulence Response. For linear airplane systems, the solution for the response to continuous turbulence may be performed entirely in the frequency domain, using the RMS response. $\bar{A}$ is defined in paragraph 25.341(b)(2) and is repeated here in modified notation for load quantity i, where:

$$\bar{A}_i = \left[\int_0^\infty |h_i(\Omega)|^2 \; \phi_I(\Omega) d\Omega \right]^{1/2}$$

or

$$\bar{A}_i = \left[\int_0^\infty \phi_I(\Omega) h_i(i\Omega) h_i^*(i\Omega) d\Omega \right]^{1/2}$$

In the above expression $\phi_I(\Omega)$ is the input von Karman power spectrum of the turbulence and is defined in Section 5.c. of this AC, $h_i(i\Omega)$ is the transfer function relating the output load quantity, i, to a unit, harmonically oscillating, one-dimensional gust field, and the asterisk superscript denotes the complex conjugate. When evaluating $\bar{A}_i$, the integration should be continued until a converged value is achieved since, realistically, the integration to infinity may be impractical. The design limit load, P_{Li}, is then defined as:

The design gust velocity, U_σ, applied in the analysis is given by the product of the reference gust velocity, $U_{\sigma REF}$, and the profile alleviation factor, F_g, as follows:

$$U_\sigma = U_{\sigma REF} F_g$$

where values for $U_{\sigma REF}$, are specified in Paragraph 25.341(b)(3) in feet per second true airspeed and F_g is defined in Paragraph 25.341(a)(6). The value of F_g is based on airplane design parameters and is a minimum value at sea level, linearly increasing to 1.0 at the certified maximum design altitude. It is identical to that used in the discrete gust analysis.

As for the discrete gust analysis, the reference continuous turbulence gust intensity, $U_{\sigma REF}$, defines the design value of the associated gust field at each altitude. In defining the value of $U_{\sigma REF}$ at each altitude, it is assumed that the airplane is flown 100% of the time at that altitude. The factor F_g is then applied to account for the probability of the airplane flying at any given altitude during its service lifetime.

It should be noted that the reference gust velocity is comprised of two components, a root-mean-square (RMS) gust intensity and a peak to RMS ratio. The separation of these components is not defined and is not required for the linear airplane analysis. Guidance is provided in Section 8.d. of this AC for generating a RMS gust intensity for a nonlinear simulation.

(2) Continuous Turbulence Response. For linear airplane systems, the solution for the response to continuous turbulence may be performed entirely in the frequency domain, using the RMS response. $\overline{A}$ is defined in paragraph 25.341(b)(2) and is repeated here in modified notation for load quantity i, where:

$$\overline{A}_i = \left[\int_0^\infty |h_i(\Omega)|^2 \; \phi_I(\Omega) d\Omega \right]^{1/2}$$

or

$$\overline{A}_i = \left[\int_0^\infty \phi_I(\Omega) h_i(i\Omega) h_i^*(i\Omega) d\Omega \right]^{1/2}$$

In the above expression $\phi_I(\Omega)$ is the input von Karman power spectrum of the turbulence and is defined in Section 5.c. of this AC, $h_i(i\Omega)$ is the transfer function relating the output load quantity, i, to a unit, harmonically oscillating, one-dimensional gust field, and the asterisk superscript denotes the complex conjugate. When evaluating $\overline{A}_i$, the integration should be continued until a converged value is achieved since, realistically, the integration to infinity may be impractical. The design limit load, P_{Li}, is then defined as:

$$P_{Li} = P_{(1\text{-}g)i} \pm P_{Ii}$$

$$= P_{(1\text{-}g)i} \pm U_\sigma \overline{A}_i$$

where U_σ is defined in Section 5.c. of this AC, and $P_{(1\text{-}g)i}$ is the 1-g steady state value for the load quantity, i, under consideration. As indicated by the formula, both positive and negative load responses should be considered when calculating limit loads.

Correlated (or equiprobable) loads can be developed using cross-correlation coefficients, ρ_{ij}, computed as follows:

$$\rho_{ij} = \frac{\int_0^\infty \phi_I(\Omega) real\left[h_i(i\Omega)h^*_j(i\Omega)\right] d\Omega}{\overline{A}_i \overline{A}_j}$$

where, 'real[...]' denotes the real part of the complex function contained within the brackets. In this equation, the lowercase subscripts, i and j, denote the responses being correlated. A set of design loads, P_{Lj}, correlated to the design limit load P_{Li}, are then calculated as follows:

$$P_{Lj} = P_{(1\text{-}g)j} \pm U_\sigma \rho_{ij} \overline{A}_j$$

The correlated load sets calculated in the foregoing manner provide balanced load distributions corresponding to the maximum value of the response for each external load quantity, i, calculated.

When calculating stresses, the foregoing load distributions may not yield critical design values because critical stress values may depend on a combination of external loads. In these cases, a more general application of the correlation coefficient method is required. For example, when the value of stress depends on two externally applied loads, such as torsion and shear, the equiprobable relationship between the two parameters forms an ellipse as illustrated in Figure 4.

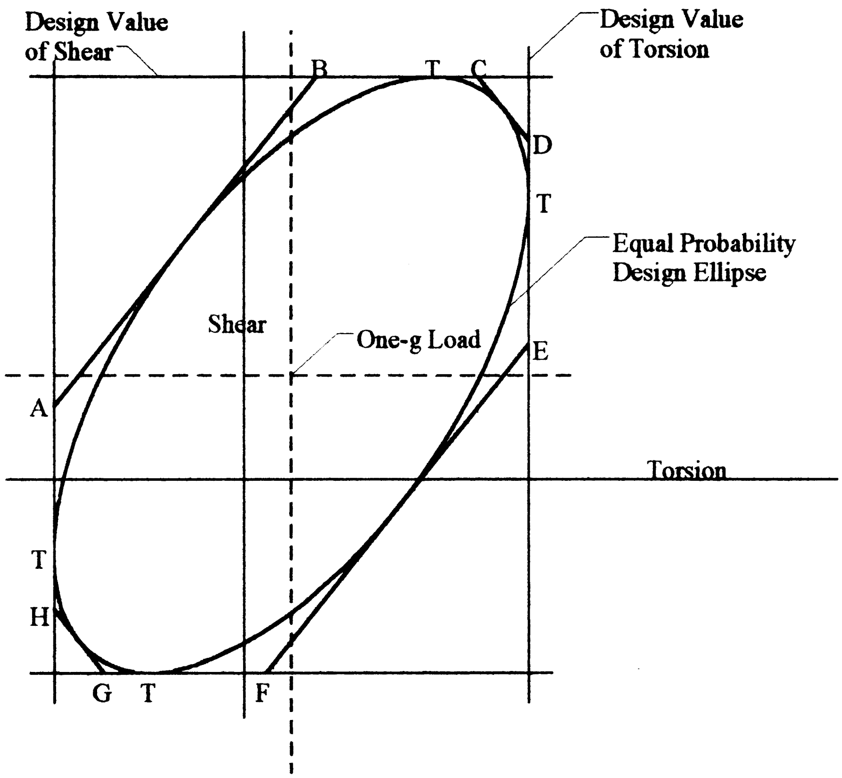

Figure-4 Equal Probability Design Ellipse

In this figure, the points of tangency, T, correspond to the expressions for correlated load pairs given by the foregoing expressions. A practical additional set of equiprobable load pairs that should be considered to establish critical design stresses are given by the points of tangency to the ellipse by lines AB, CD, EF and GH. These additional load pairs are given by the following expressions (where i = torsion and j = shear):

For tangents to lines AB and EF

$$P_{Li} = P_{(1-g)i} \;+/-\; \bar{A}_i U_\sigma [(1 - \rho_{ij})/2]^{1/2}$$

$$\text{and} \quad P_{Lj} = P_{(1-g)j} \;-/+\; \bar{A}_j U_\sigma [(1 - \rho_{ij})/2]^{1/2}$$

For tangents to lines CD and GH

$$P_{Li} = P_{(1-g)i} \pm \bar{A}_i U_\sigma [(1 + \rho_{ij})/2]^{1/2}$$

$$\text{and} \quad P_{Lj} = P_{(1-g)j} \pm \bar{A}_j U_\sigma [(1 + \rho_{ij})/2]^{1/2}$$

All correlated or equiprobable loads developed using correlation coefficients will provide balanced load distributions.

A more comprehensive approach for calculating critical design stresses that depend on a combination of external load quantities is to evaluate directly the transfer function for the stress quantity of interest from which can be calculated the gust response function, the value for RMS response, $\bar{A}$, and the design stress values $P_{(1-g)} \pm U_\sigma \bar{A}$.

6. AIRPLANE MODELING CONSIDERATIONS

a. General. The procedures presented in this section generally apply for airplanes having aerodynamic and structural properties and flight control systems that may be reasonably or conservatively approximated using linear analysis methods for calculating limit load. Additional guidance material is presented in Section 8 of this AC for airplanes having properties and/or systems not reasonably or conservatively approximated by linear analysis methods.

b. Structural Dynamic Model. The model should include both rigid body and flexible airplane degrees of freedom. If a modal approach is used, the structural dynamic model should include a sufficient number of flexible airplane modes to ensure both convergence of the modal superposition procedure and that responses from high frequency excitations are properly represented.

Most forms of structural modeling can be classified into two main categories: (1) the so-called "stick model" characterised by beams with lumped masses distributed along their lengths, and (2) finite element models in which all major structural components (frames, ribs, stringers, skins) are represented with mass properties defined at grid points. Regardless of the approach taken for the structural modeling, a minimum acceptable level of sophistication, consistent with configuration complexity, is necessary to represent satisfactorily the critical modes of deformation of the primary structure and control surfaces. Results from the models should be compared to test data as outlined in Section 9.b. of this AC in order to validate the accuracy of the model.

c. Structural Damping. Structural dynamic models may include damping properties in addition to representations of mass and stiffness distributions. In the absence of better information it will normally be acceptable to assume 0.03 (i.e. 1.5% equivalent critical viscous damping) for all flexible modes. Structural damping may be increased over the 0.03 value to be consistent with the high structural response levels caused by extreme gust intensity, provided justification is given.

d. Gust and Motion Response Aerodynamic Modeling. Aerodynamic forces included in the analysis are produced by both the gust velocity directly, and by the airplane response.

Aerodynamic modeling for dynamic gust response analyses requires the use of unsteady two-dimensional or three-dimensional panel theory methods for incompressible or compressible flow. The choice of the appropriate technique depends on the complexity of the aerodynamic configuration, the dynamic motion of the surfaces under investigation and the flight speed envelope of the airplane. Generally, three-dimensional panel methods achieve better modeling of the aerodynamic interference between lifting surfaces. The model should have a sufficient number of aerodynamic degrees of freedom to properly represent the steady and unsteady aerodynamic distributions under consideration.

The buildup of unsteady aerodynamic forces should be represented. In two-dimensional unsteady analysis this may be achieved in either the frequency domain or the time domain through the application of oscillatory or indicial lift functions, respectively. Where three-dimensional panel aerodynamic theories are to be applied in the time domain (e.g. for nonlinear gust solutions), an approach such as the 'rational function approximation' method may be employed to transform frequency domain aerodynamics into the time domain.

Oscillatory lift functions due to gust velocity or airplane response depend on the reduced frequency parameter, k. The maximum reduced frequency used in the generation of the unsteady aerodynamics should include the highest frequency of gust excitation and the highest structural frequency under consideration. Time lags representing the effect of the gradual penetration of the gust field by the airplane should also be accounted for in the buildup of lift due to gust velocity.

The aerodynamic modeling should be supported by tests or previous experience as indicated in Section 9.d. of this AC. Primary lifting and control surface distributed aerodynamic data are commonly adjusted by weighting factors in the dynamic gust response analyses. The weighting factors for steady flow ($k = 0$) may be obtained by comparing wind tunnel test results with theoretical data. The correction of the aerodynamic forces should also ensure that the rigid body motion of the airplane is accurately represented in order to provide satisfactory short period and Dutch roll frequencies and damping ratios. Corrections to primary surface aerodynamic loading due to control surface deflection should be considered. Special attention should also be given to control surface hinge moments and to fuselage and nacelle aerodynamics because viscous and other effects may require more extensive adjustments to the theoretical coefficients. Aerodynamic gust forces should reflect weighting factor adjustments performed on the steady or unsteady motion response aerodynamics.

e. Gyroscopic Loads. As specified in Paragraph 25.371, the structure supporting the engines and the auxiliary power units should be designed for the gyroscopic loads induced by both discrete gusts and continuous turbulence. The gyroscopic loads for turbopropellers and turbofans may be calculated as an integral part of the solution process by including the gyroscopic terms in the equations of motion or the gyroscopic loads can be superimposed after the solution of the equations of motion. Propeller and fan gyroscopic coupling forces (due to rotational direction) between symmetric and antisymmetric modes need not be taken into account if the coupling forces are shown to be negligible.

The gyroscopic loads used in this analysis should be determined with the engine or auxiliary power units at maximum continuous rpm. The mass polar moment of inertia used in calculating gyroscopic inertia terms should include the mass polar moments of inertia of all significant rotating parts taking into account their respective rotational gearing ratios and directions of rotation.

f. Control Systems. Gust analyses of the basic configuration should include simulation of any control system for which interaction may exist with the rigid body response, structural dynamic response or external loads. If possible, these control systems should be uncoupled such that the systems which affect "symmetric flight" are included in the vertical gust analysis and those which affect "antisymmetric flight" are included in the lateral gust analysis.

The control systems considered should include all relevant modes of operation. Failure conditions should also be analyzed for any control system which influences the design loads in accordance with Paragraph 25.302, Appendix K.

The control systems included in the gust analysis may be assumed to be linear if the impact of the nonlinearity is negligible, or if it can be shown by analysis on a similar airplane/control system that a linear control law representation is conservative. If the control system is significantly nonlinear, and a conservative linear approximation to the control system cannot be developed, then the effect of the control system on the airplane responses should be evaluated in accordance with Section 8.0 of this AC.

g. Stability. Solutions of the equations of motion for either discrete gusts or continuous turbulence require the dynamic model be stable. This applies for all modes, except possibly for very low frequency modes which do not affect load responses, such as the phugoid mode. (Note that the short period and Dutch roll modes do affect load responses). A stability check should be performed for the dynamic model using conventional stability criteria appropriate for the linear or nonlinear system in question, and adjustments should be made to the dynamic model, as required, to achieve appropriate frequency and damping characteristics.

If control system models are to be included in the gust analysis it is advisable to check that the following characteristics are acceptable and are representative of the airplane;

- static margin of the unaugmented airplane
- dynamic stability of the unaugmented airplane
- the static aeroelastic effectiveness of all control surfaces utilised by any feed-back control system
- gain and phase margins of any feedback control system coupled with the airplane rigid body and flexible modes
- the aeroelastic flutter and divergence margins of the unaugmented airplane, and also for any feedback control system coupled with the airplane.

7. DYNAMIC LOADS

a. General. This section describes methods for formulating and solving the airplane equations of motion and extracting dynamic loads from the airplane response. The airplane equations of motion are solved in either physical or modal coordinates and include all terms important in the loads calculation including stiffness, damping, mass, and aerodynamic forces due to both airplane motions and gust excitation. Generally the aircraft equations are solved in modal coordinates. For the purposes of describing the solution of these equations in the remainder of this AC, modal coordinates will be assumed. A sufficient number of modal coordinates should be included to ensure that the loads extracted provide converged values.

b. Solution of the Equations of Motion. Solution of the equations of motion can be achieved through a number of techniques. For the continuous turbulence analysis, the equations of motion are generally solved in the frequency domain. Transfer functions which relate the output response quantity to an input harmonically oscillating gust field are generated and these transfer functions are used (in Section 5.c. of this AC) to generate the RMS value of the output response quantity.

There are two primary approaches used to generate the output time histories for the discrete gust analysis; (1) by explicit integration of the airplane equations of motion in the time domain, and (2) by frequency domain solutions which can utilize Fourier transform techniques.

c. Extraction of Loads and Responses. The output quantities that may be extracted from a gust response analysis include displacements, velocities and accelerations at structural locations; load quantities such as shears, bending moments and torques on structural components; and stresses and shear flows in structural components. The calculation of the physical responses is given by a modal superposition of the displacements, velocities and accelerations of the rigid and elastic modes of vibration of the airplane structure. The number of modes carried in the summation should be sufficient to ensure converged results.

A variety of methods may be used to obtain physical structural loads from a solution of the modal equations of motion governing gust response. These include the Mode Displacement method, the Mode Acceleration method, and the Force Summation method. All three methods are capable of providing a balanced set of airplane loads. If an infinite number of modes can be considered in the analysis, the three will lead to essentially identical results.

The Mode Displacement method is the simplest. In this method, total dynamic loads are calculated from the structural deformations produced by the gust using modal superposition. Specifically, the contribution of a given mode is equal to the product of the load associated with the normalized deformed shape of that mode and the value of the displacement response given by the associated modal coordinate. For converged results, the Mode Displacement method may need a significantly larger number of modal coordinates than the other two methods.

In the Mode Acceleration method, the dynamic load response is composed of a static part and a dynamic part. The static part is determined by conventional static analysis (including rigid body "inertia relief"), with the externally applied gust loads treated as static loads. The dynamic part is computed by the superposition of appropriate modal quantities, and is a function of the number of modes carried in the solution. The quantities to be superimposed involve both motion response forces and acceleration responses (thus giving this method its name). Since the static part is determined completely and independently of the number of normal modes carried, adequate accuracy may be achieved with fewer modes than would be needed in the Mode Displacement method.

The Force Summation method is the most laborious and the most intuitive. In this method, physical displacements, velocities and accelerations are first computed by superposition of the modal responses. These are then used to determine the physical inertia forces and other motion dependent forces. Finally, these forces are added to the externally applied forces to give the total dynamic loads acting on the structure.

If balanced airplane load distributions are needed from the discrete gust analysis, they may be determined using time correlated solution results. Similarly, as explained in Section 5.c of this AC, if balanced airplane load distributions are needed from the continuous turbulence analysis, they may be determined from equiprobable solution results obtained using cross-correlation coefficients.

8. NONLINEAR CONSIDERATIONS

a. General. Any structural, aerodynamic or automatic control system characteristic which may cause airplane response to discrete gusts or continuous turbulence to become nonlinear with respect to intensity or shape should be represented realistically or conservatively in the calculation of loads. While many minor nonlinearities are amenable to a conservative linear solution, the effect of major nonlinearities cannot usually be quantified without explicit calculation.

The effect of nonlinearities should be investigated above limit conditions to assure that the system presents no anomaly compared to behaviour below limit conditions, in accordance with Paragraph 25.302 Appendix K(b)(2).

b. Structural and Aerodynamic Nonlinearity. A linear elastic structural model, and a linear (unstalled) aerodynamic model are normally recommended as conservative and acceptable for the unaugmented airplane elements of a loads calculation. Aerodynamic models may be refined to take account of minor nonlinear variation of aerodynamic distributions, due to local separation etc., through simple linear piecewise solution. Local or complete stall of a lifting surface would constitute a major nonlinearity and should not be represented without account being taken of the influence of rate of change of incidence, i.e., the so-called 'dynamic stall' in which the range of linear incremental aerodynamics may extend significantly beyond the static stall incidence.

c. Automatic Control System Nonlinearity. Automatic flight control systems, autopilots, stability control systems and load alleviation systems often constitute the primary source of nonlinear response. For example,

- non-proportional feedback gains
- rate and amplitude limiters
- changes in the control laws, or control law switching
- hysteresis
- use of one-sided aerodynamic controls such as spoilers
- hinge moment performance and saturation of aerodynamic control actuators

The resulting influences on response will be airplane design dependent, and the manner in which they are to be considered will normally have to be assessed for each design.

Minor influences such as occasional clipping of response due to rate or amplitude limitations, where it is symmetric about the stabilized 1-g condition, can often be represented through quasi-linear modeling techniques such as describing functions or use of a linear equivalent gain.

Major, and unsymmetrical influences such as application of spoilers for load alleviation, normally require explicit simulation, and therefore adoption of an appropriate solution based in the time domain.

The influence of nonlinearities on one load quantity often runs contrary to the influence on other load quantities. For example, an aileron used for load alleviation may simultaneously relieve wing bending moment whilst increasing wing torsion. Since it may not be possible to represent such features conservatively with a single airplane model, it may be conservatively acceptable to consider loads computed for two (possibly linear) representations which bound the realistic condition. Another example of this approach would be separate representation of continuous turbulence response for the two control law states to cover a situation where the airplane may occasionally switch from one state to another.

d. Nonlinear Solution Methodology. Where explicit simulation of nonlinearities is required, the loads response may be calculated through time domain integration of the equations of motion.

For the tuned discrete gust conditions of Paragraph 25.341(a), limit loads should be identified by peak values in the nonlinear time domain simulation response of the airplane model excited by the discrete gust model described in Section 5.b. of this AC.

For time domain solution of the continuous turbulence conditions of Paragraph 25.341(b), a variety of approaches may be taken for the specification of the turbulence input time history and the mechanism for identifying limit loads from the resulting responses.

It will normally be necessary to justify that the selected approach provides an equivalent level of safety as a conventional linear analysis and is appropriate to handle the types of nonlinearity on the aircraft. This should include verification that the approach provides adequate statistical significance in the loads results.

A methodology based upon stochastic simulation has been found to be acceptable for load alleviation and flight control system nonlinearities. In this simulation, the input is a long, Gaussian, pseudo-random turbulence stream conforming to a von Karman spectrum with a root-mean-square (RMS) amplitude of 0.4 times U_σ (defined in Section 5.C.1 of this AC). The value of limit load is that load with the same probability of exceedance as $\bar{A}U_\sigma$ of the same load quantity in a linear model. This is illustrated graphically in Figure 5. When using an analysis of this type, exceedance curves should be constructed using incremental load values up, or just beyond the limit load value.

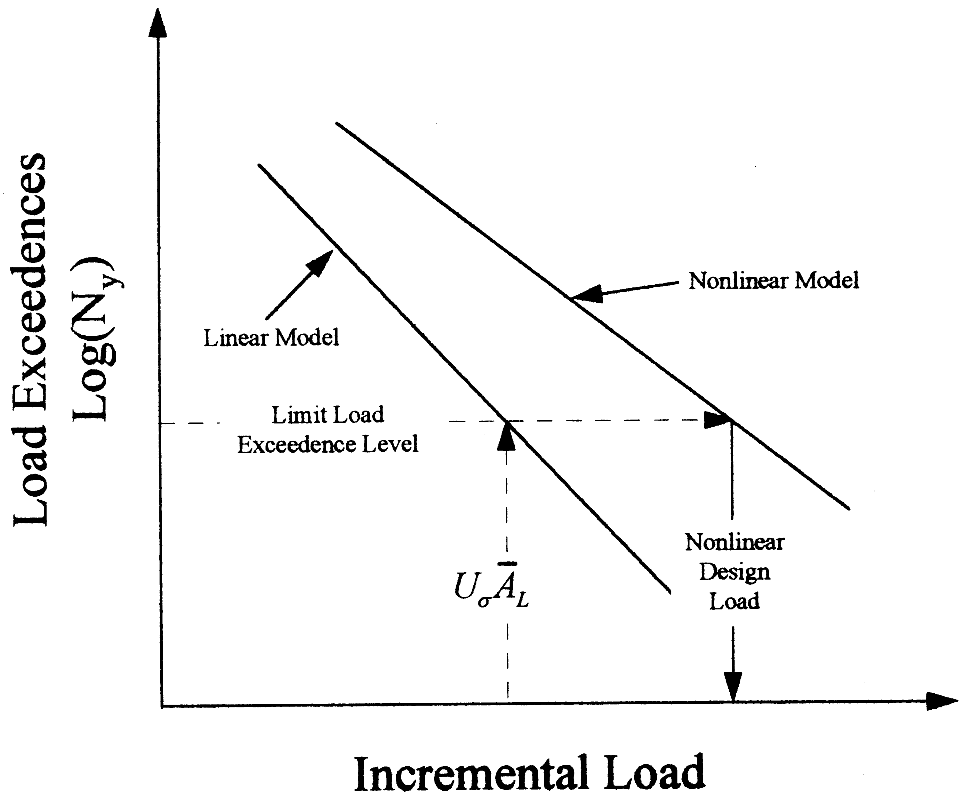

Figure-5 Establishing Limit Load for a Nonlinear Airplane

The nonlinear simulation may also be performed in the frequency domain if the frequency domain method is shown to produce conservative results. Frequency domain methods include, but are not limited to, Matched Filter Theory and Equivalent Linearization.

9. ANALYTICAL MODEL VALIDATION

a. General. The intent of analytical model validation is to establish that the analytical model is adequate for the prediction of gust response loads. The following sections discuss acceptable but not the only methods of validating the analytical model. In general, it is not intended that specific testing be required to validate the dynamic gust loads model.

b. Structural Dynamic Model Validation. The methods and test data used to validate the flutter analysis models presented in AC 25.629-1A should also be applied to validate the gust analysis models. These procedures are addressed in the AC 25.629-1A.

c. Damping Model Validation. In the absence of better information it will normally be acceptable to assume 0.03 (i.e. 1.5% equivalent critical viscous damping) for all flexible modes. Structural damping may be increased over the 0.03 value to be consistent with the high structural response levels caused by extreme gust intensity, provided justification is given.

d. Aerodynamic Model Validation. Aerodynamic modeling parameters fall into two categories:

(i) steady or quasisteady aerodynamics governing static aeroelastic and flight dynamic airload distributions

(ii) unsteady aerodynamics which interact with the flexible modes of the airplane.

Flight stability aerodynamic distributions and derivatives may be validated by wind tunnel tests, detailed aerodynamic modeling methods (such as CFD) or flight test data. If detailed analysis or testing reveals that flight dynamic characteristics of the airplane differ significantly from those to which the gust response model have been matched, then the implications on gust loads should be investigated.

The analytical and experimental methods presented in AC 25.629-1A for flutter analyses provide acceptable means for establishing reliable unsteady aerodynamic characteristics both for motion response and gust excitation aerodynamic force distributions. The aeroelastic implications on airplane flight dynamic stability should also be assessed.

e. Control System Validation. If the airplane mathematical model used for gust analysis contains a representation of any feedback control system, then this segment of the model should be validated. The level of validation that should be performed depends on the complexity of the system and the particular airplane response parameter being controlled. Systems which control elastic modes of the airplane may require more validation than those which control the airplane rigid body response. Validation of elements of the control system (sensors, actuators, anti-aliasing filters, control laws, etc.) which have a minimal effect on the output load and response quantities under consideration can be neglected.

It will normally be more convenient to substantiate elements of the control system independently, i.e. open loop, before undertaking the validation of the closed loop system.

(1) System Rig or Airplane Ground Testing. Response of the system to artificial stimuli can be measured to verify the following:

- The transfer functions of the sensors and any pre-control system anti-aliasing or other filtering.
- The sampling delays of acquiring data into the control system.
- The behavior of the control law itself.
- Any control system output delay and filter transfer function.
- The transfer functions of the actuators, and any features of actuation system performance characteristics that may influence the actuator response to the maximum demands that might arise in turbulence; e.g. maximum rate of deployment, actuator hinge moment capability, etc.

If this testing is performed, it is recommended that following any adaptation of the model to reflect this information, the complete feedback path be validated (open loop) against measurements taken from the rig or ground tests.

(2) Flight Testing. The functionality and performance of any feedback control system can also be validated by direct comparison of the analytical model and measurement for input stimuli. If this testing is performed, input stimuli should be selected such that they exercise the features of the control system and the interaction with the airplane that are significant in the use of the mathematical model for gust load analysis. These might include:

- Airplane response to pitching and yawing maneuver demands.
- Control system and airplane response to sudden artificially introduced demands such as pulses and steps.
- Gain and phase margins determined using data acquired within the flutter test program. These gain and phase margins can be generated by passing known signals through the open loop system during flight test.